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CHOICE AND DELAY OF REINFORCEMENT: EFFECTS OF TERMINAL-LINK STIMULUS AND RESPONSE CONDITIONS

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In two experiments, pigeons were exposed to concurrent-chains schedules in which a single initial-link variable-interval schedule led to access to terminal links composed of fixed-interval or fixed-delay schedules. In Experiment 1, an 8-s (or 16-s) delay to reinforcement was associated with the standard key, while reinforcer delay values associated with the experimental key were varied from 4 to 32 s. The results of Experiment 1 showed undermatching of response ratios to delay ratios with terminal-link fixed-delay schedules, whereas in some pigeons matching or overmatching was evident with the fixed-interval schedules. In Experiment 2, one pair of reinforcer delay values, either 8 versus 16 s or 16 versus 32 s, was used. In the first condition of Experiment 2, different delays were associated with different keylight stimuli (cued condition). In the second condition, different terminal-link delays were associated with the same stimulus, either a blackout (uncued-blackout condition) or a white key (uncued-white condition). To examine the role of responses emitted during delays, the keys were retracted during a delay (key-absent condition) in the third condition and responses were required by a fixed-interval schedule in the fourth condition. Experiment 2 demonstrated that the choice proportions for the shorter delay were more extreme in the cued condition than in the uncued-blackout condition, and that the response requirement imposed by the fixed-interval schedules did not affect choice of the shorter delay, nor did the key-absent and key-present conditions. These results indicate that the keylight-stimulus conditions affected preference for the shorter of two delays and that the findings obtained in Experiment 1 depended mainly on the keylight-stimulus conditions of the terminal links (i.e., the conditioned reinforcing value of the terminal-link stimuli).

Key words: choice, delay of reinforcement, generalized matching law, conditioned reinforcement, concurrent-chains schedules, fixed-interval schedules, fixed-time schedules, key peck, pigeons

Recent studies of choice between delayed reinforcers, using a concurrent-chains procedure, have shown that preference for the shorter of two delays increases when the absolute size of the delays is increased (Duncan & Fantino, 1970; Fantino & Royalty, 1987; Gentry & Marr, 1980; MacEwen, 1972; Williams & Fantino, 1978). These results are inconsistent with the notion that choice behavior matches relative immediacy (the reciprocal of delay) of reinforcement. This notion was first established by Chung and Herrnstein (1967), who gave pigeons a choice between paired delays (the durations of a blackout period) in a concurrent schedule in which two variable-interval (VI) schedules were concurrently available, each leading to a blackout period followed by the presentation of a reinforcer. In their procedure, an 8-s (or 16-s) delay was used in one key (standard key), while delay values were varied from 1 to 30 s in the other key (experimental key). They found that relative response matched to relative delay (or relative immediacy) of reinforcement.

To investigate the effect of differences in the stimulus conditions between terminal-link fixed-delay (FD) and terminal-link fixed-interval (FI) schedules, Williams and Fantino (1978), using pigeons, examined the stimulus conditions of terminal links in concurrent-chains procedures in which a single VI schedule arranged entry into the terminal links, and the terminal-link stimuli were associated with different delays of reinforcement defined by FI schedules. They compared a cued condition with the corresponding uncued condition under several pairs of delays, in which the longer delay was twice as long as the paired shorter delay (e.g., FI 5 s vs. FI 10 s). In the cued condition, choice responses produced different stimuli associated with each delay, whereas in the uncued condition, choice responses produced the same stimulus (i.e., white-key illumination) for each delay. Thus, the uncued condition was similar to the condition used by Chung and Herrnstein (1967) in that the differential consequence of the choice response

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was only the overall time to reinforcement. They found that choice proportions for the shorter delay increased with increases in the absolute value of the paired delays in both cued and uncued conditions, although choice proportions were higher in the cued condition than in the uncued condition.

Although these findings cannot explain results of the Chung and Herrnstein (1967) study that were inconsistent with those of other studies (e.g., MacEwen, 1972), Williams and Fantino (1978) applied the following generalized matching equation (Baum, 1974) to the data of Chung and Herrnstein:

$$(R_1/R_2) = b[(1/D_1)/(1/D_2)]^a = b(D_2/D_1)^a, \quad (1)$$

where D is the reinforcer delay, $1/D$ is the immediacy of reinforcement, R is the number of responses to that alternative, and a and b are empirical constants. If Equation 1 is logarithmically transformed, we obtain

$$\log(R_1/R_2) = a \log(D_2/D_1) + \log b. \quad (2)$$

A bias is present when b is not equal to one. Strict matching occurs when a is equal to one. Undermatching occurs if a is less than one, and overmatching occurs if a is greater than one. Thus analyzed, Williams and Fantino (1978) found that overmatching occurred for the longer delay values (i.e., longer than 8 s), whereas undermatching occurred for the shorter delay values (i.e., shorter than 8 s) in the 8-s delay group of the Chung and Herrnstein (1967) study.

Further, it should be pointed out that the effects of delayed reinforcers were confounded with relative frequency of reinforcement in the study of Chung and Herrnstein (1967). In their experiment, relative frequency of reinforcement was not equated on two alternatives because two independent schedules (e.g., VI schedules) were used. Because relative frequency of reinforcement depended, to some extent, on a subject's responding, the effects of delayed reinforcers were confounded with relative frequency of reinforcement. To overcome this problem, several studies of the effects of delayed reinforcers employed a single VI scheduling procedure (Stubbs & Pliskoff, 1969) to equate relative reinforcement rate on two alternatives (Gentry & Marr, 1980; MacEwen, 1972; Williams & Fantino, 1978). Also, additional timeout periods after the shorter delays have been used to equate overall rates of reinforcement on two alternatives (cf. Chung, 1965; Gentry & Marr, 1980).

The stimuli associated with delays (e.g., the terminal links of concurrent chains) seem to play an important role, as suggested by the Williams and Fantino (1978) study. They showed that choice proportions in the uncued (same stimulus) condition were reduced relative to those in the cued (different stimuli) condition. Similar results were obtained by Navarick and Fantino (1976), who showed that preference for the shorter delay was sometimes reduced to indifference when the same stimulus (blackout) was used for each delay. A recent study by Dunn, Williams, and Royalty (1987) showed the important role of terminal-link stimuli as determinants of preference in the initial links of a concurrent-chains procedure. These findings indicated that the role of the stimulus associated with each delay must be considered, as well as the delays to the reinforcer per se. Therefore, one problem is to what extent such stimulus conditions substantially affect the matching relation to delayed reinforcers.

The procedures used by Williams and Fantino (1978) differed from those used by Chung and Herrnstein (1967) in several ways. First, in the former study, the uncued condition employed keylight (white) illumination for the delay period rather than a blackout. Second, responses were required during the delay period in the FI schedules but not in the FD schedules. Third, there was no position cue in the cued and uncued conditions; in the uncued condition, for example, entry from either initial link resulted in illumination of one of the response keys with white light, regardless of which response key during the initial link had produced the terminal link. Fourth, a single VI schedule was used in the initial links instead of two independent VI schedules.

With respect to the first two factors, Williams and Fantino (1978) noted that neither of these differences seemed of major importance in light of Neuringer's (1969) results, which showed that pigeons are indifferent between blackout and FI schedules in the terminal links. In Neuringer's procedure, however, the effects of stimulus conditions were confounded with the response requirement imposed by FI schedules. Therefore, it is of particular interest to examine the effects of these two factors separately on choice. In studies of choice between delayed reinforcers, there have been three different combinations of stimulus and response conditions in terminal links. First, the keylight was presented for each delay, and no responses were required in fixed-time (FT) terminal-link schedules (e.g., Williams & Fantino, 1978); and second, the keylight was not presented (i.e., blackout) and responses were not required in FD terminal-link schedules (e.g., Davison, Alsop, & Denison, 1988); third, the keylight was presented for each delay, and responses were required in FI terminal-link schedules (e.g., MacEwen, 1972). Thus, preferences obtained under these terminal-link schedules may have been determined in part by the effects of stimulus and/or response conditions.

The present experiments were designed to examine these procedural differences to see whether matching of relative response rates to relative delayed reinforcers does occur. Experiment 1 attempted to replicate the results of the Chung and Herrnstein (1967) study while eliminating the complicating effects of changes in relative rate of reinforcement. It compared FI terminal-link schedules with FD terminal-link schedules under paired delays of various durations, as in Chung and Herrnstein (1967). Experiment 2 employed only one pair of delay values and examined several terminal-link schedule conditions to determine the effects of keylight stimulus and response conditions.

EXPERIMENT 1

METHOD

Subjects

Six homing pigeons were maintained at about 80% of their free-feeding weights by additional feeding after each experimental session. Water and grit were available in the home cages at all times. All birds had previous experimental histories with multiple schedules.

Apparatus

A standard experimental chamber (30 cm by 30 cm by 30 cm) with two response keys was used. Each key was transilluminated with white, red, and green lights except during a blackout period and the operation of a hopper. The keys required a minimum force of 0.10 N to operate. The opening of the hopper that allowed 3-s access to grain was located midway between the two keys and 16 cm below them. Masking noise was provided by an exhaust fan throughout the experiment. A microcomputer system (NEC PC-8801), in an adjacent room, controlled the experiment and recorded events.

Procedure

Initially, all pigeons were exposed to a concurrent-schedules procedure in which reinforcement was given equally often for two alternatives. After performance was approximately stabilized, a concurrent-chains schedule was introduced with two different types of terminal-link schedule, FD and FI schedules. The subjects were first exposed to the FD terminal-link condition and then to the FI terminal-link condition. Each session was terminated when 30 reinforcers had been obtained.

During the initial link of the concurrent-chains schedule (i.e., choice phase), each key was always illuminated with white. After entry into either of the terminal links (i.e., delay period), both keys were darkened in the FD terminal-link condition, whereas only the key not pecked was darkened in the FI terminal-link condition and the other key remained white. Entry into either of the terminal links was arranged by the single VI scheduling procedure. Each interval of the VI tape was derived from the distribution of Fleshler and Hoffman (1962). As each interval timed out, the timer stopped and reinforcement was assigned quasi-randomly, with equal probability to either the left or the right key (Stubbs & Pliskoff, 1969). In this procedure, therefore, each alternative was presented equally often during each session. The next response on the appropriate key initiated the delay period defined by the value of the terminal-link schedule. After the delay, reinforcement (3 s access to grain) was available on the terminal-link schedule. Then an additional timeout in blackout followed.

Six pigeons were divided into two groups; one received a standard 8-s delay condition and the other received a 16-s delay condition. The value of the terminal-link schedule imposed on the right key (the standard key) was 8 s in one group and 16 s in the other group, while the values of the terminal-link schedule imposed on the left key were varied across conditions. The values of the delays used on the experimental key were 4, 8, 16, 24, and 32 s (the value of 32 s was used only for the constant 16-s delay group). All pigeons were initially exposed to an equal delays condition (i.e., 8 s vs. 8 s for the standard 8-s delay group and 16 s vs. 16 s for the standard 16-s delay group). The order of the conditions for each group is described in Table 1.

To equate the overall reinforcement rate for two alternatives, the total duration of the terminal links was equalized on two keys. Total duration of each terminal link was 30 s for the 8-s delay group and 40 s for the 16-s delay group, and was arranged by adding an appropriate period (blackout) to the end of the hopper presentation. In the 4-s versus 8-s condition, for example, the total duration of 30 s for the left key consisted of a 4-s delay period and a 3-s hopper presentation with 23 s of additional blackout, whereas for the right key, the total duration of 30 s consisted of an 8-s delay interval and a 3-s hopper presentation with 19 s of additional blackout. Pecking either key had no effect during blackout. At the end of the additional period, the response keys were again illuminated, and the VI timer restarted.

Each condition continued for a minimum of 18 sessions until the following stability criterion was achieved: The choice proportion (calculated by dividing the initial-link responses for the left key by the total initial-link responses) for the last nine sessions were divided into three blocks of three sessions each. The choice proportion was considered stable when the means of these blocks did not differ from each other by more than .05, and showed no monotonically increasing or decreasing trend in the block means.

Results

Table 1 shows the mean number of responses for both initial and terminal links, mean choice proportions and standard deviations for each pigeon, and the order of conditions. All data were averaged over the last nine sessions for each condition. For all pigeons, choice proportions for the shorter delay (i.e., initial-link responses for shorter delay divided by total initial-link responses) usually increased when the terminal links changed from FD to FI schedules.

Figure 1 shows the logarithm of the ratio of choice responses as a function of the logarithm of the ratio of delays in the FD and FI terminal-link conditions for each pigeon. The dashed lines show the locus of strict matching between the response ratio and delay ratio. A linear regression was applied to the log-transformed data. The solid lines show a least squares fit to the data. The value of r^2 is the coefficient of determination.

For the FD terminal-link conditions, the obtained function for each pigeon had a slope less than one; the values of the slope obtained ranged from 0.50 to 0.80 for the 8-s standard delay group and from 0.39 to 0.86 for the 16-s standard delay group. The percentages of data variance accounted for ranged from 60% to 97% for the 8-s delay group and from 86% to 98% for the 16-s delay group. Thus, all pigeons undermatched their response ratios to delay ratios in the FD terminal-link condition.

When the condition was changed to the FI terminal-link condition, the values of the slope of the function obtained increased for all pigeons. For the FI condition, the values of the slope obtained ranged from 0.63 to 1.23 for the 8-s standard delay group and from 0.97 to 2.08 for the 16-s standard delay group. The percentages of data variance accounted for ranged from 91% to 99% for the 8-s delay group and from 94% to 95% for the 16-s delay group. Therefore, 4 pigeons showed matching or overmatching of response ratios to delay ratios, although 2 pigeons in the 8-s delay group still showed undermatching.

Discussion

The present experiment eliminated the complicating effects of rate of reinforcement and demonstrated that all pigeons undermatched their response ratios to delay ratios in the FD terminal-link condition, whereas in the FI terminal-link condition 4 of the 6 pigeons showed matching or overmatching of the response ratios to delay ratios. Thus, the present results indicate that sensitivity to the ratio of delays was higher in the FI schedules than in the FD schedules. This finding is inconsistent with those obtained from Chung and Herrnstein (1967) but is consistent with those obtained in the Gentry and Marr (1980) study, in which rate of reinforcement was equated on two alternatives by using a single VI procedure and an additional blackout period after the

Table 1

Values of FD and FI terminal-link schedules for the left (L) and right (R) keys, session and order of conditions (in parentheses), choice proportions for the shorter delay and standard deviation (in parentheses), and number of responses for each key in the initial and terminal links. Data are averaged over the last nine sessions for each condition.

Terminal-link conditions			Subject											
			MP8107[a]				MP8109[a]				MP8114[a]			
Schedules	Delays (s) L	R	Sessions and order of condition	Choice proportion	Initial-link responses (L/R)	Terminal-link responses (L/R)	Sessions and order of condition	Choice proportion	Initial-link responses (L/R)	Terminal-link responses (L/R)	Sessions and order of condition	Choice proportion	Initial-link responses (L/R)	Terminal-link responses (L/R)
FD	4	8	20 (2)	.66 (.04)	682/356	—	27 (3)	.62 (.02)	486/293	—	18 (3)	.63 (.05)	544/318	—
	8	8	37 (1)	.47 (.03)	485/538	—	39 (1)	.40 (.03)	292/446	—	30 (1)	.47 (.03)	345/389	—
	16	8	22 (4)	.60 (.03)	411/627	—	18 (2)	.69 (.02)	273/594	—	20 (2)	.57 (.03)	345/452	—
	24	8	41 (3)	.70 (.03)	366/850	—	36 (4)	.59 (.03)	367/518	—	53 (4)	.60 (.02)	326/492	—
FI	4	8	31 (6)	.63 (.05)	499/302	47/88	30 (7)	.65 (.04)	446/236	24/33	39 (7)	.64 (.04)	519/291	79/130
	8	8	26 (5)	.47 (.05)	266/305	69/93	41 (5)	.48 (.05)	348/378	45/46	18 (5)	.48 (.02)	426/465	165/169
	16	8	—	—	—	—	37 (6)	.62 (.04)	320/515	75/51	19 (6)	.66 (.03)	247/488	252/111
	24	8	20 (7)	.84 (.04)	104/552	153/93	30 (8)	.62 (.03)	239/394	178/33	24 (8)	.64 (.03)	244/438	377/137

Table 1

(*Extended*)

Terminal-link conditions			Subject											
			MP8101				MP8111				MP8126			
Schedules	Delays (s) L	R	Sessions and order of condition	Choice proportion	Initial-link responses (L/R)	Terminal-link responses (L/R)	Sessions and order of condition	Choice proportion	Initial-link responses (L/R)	Terminal-link responses (L/R)	Sessions and order of condition	Choice proportion	Initial-link responses (L/R)	Terminal-link responses (L/R)
FD	4	16	23 (5)	.75 (.02)	662/226	14/41	18 (4)	.61 (.03)	526/337	0/0	20 (4)	.62 (.02)	469/290	22/27
	8	16	27 (3)	.64 (.03)	498/283	15/26	18 (2)	.57 (.02)	489/367	1/0	28 (2)	.58 (.04)	424/308	7/10
	16	16	24 (1)	.47 (.03)	276/309	81/99	29 (1)	.49 (.05)	286/301	2/1	18 (1)	.52 (.04)	342/317	3/5
	24	16	19 (2)	.60 (.05)	390/586	35/41	20 (3)	.57 (.03)	333/445	0/0	21 (3)	.64 (.04)	248/437	14/25
	32	16	21 (4)	.56 (.02)	355/461	21/34	37 (5)	.58 (.04)	253/344	0/1	28 (5)	.61 (.03)	201/319	5/10
FI	4	16	29 (10)	.94 (.02)	1,682/106	261/638	40 (9)	.82 (.02)	821/180	120/334	32 (9)	.83 (.04)	540/115	110/204
	8	16	34 (8)	.73 (.02)	1,344/505	269/594	31 (7)	.77 (.03)	455/135	164/240	22 (7)	.79 (.03)	343/89	105/183
	16	16	20 (6)	.50 (.04)	914/927	660/843	18 (6)	.52 (.04)	408/369	347/271	20 (6)	.49 (.06)	221/230	180/190
	24	16	25 (7)	.76 (.03)	368/1,159	327/435	29 (8)	.56 (.04)	180/234	319/331	57 (8)	.66 (.04)	169/328	303/168
	32	16	37 (9)	.90 (.03)	170/1,489	1,051/903	31 (10)	.57 (.04)	292/598	353/328	18 (10)	.77 (.06)	72/258	276/159

[a] In these pigeons, responses were not measured during the terminal links in the FD condition.

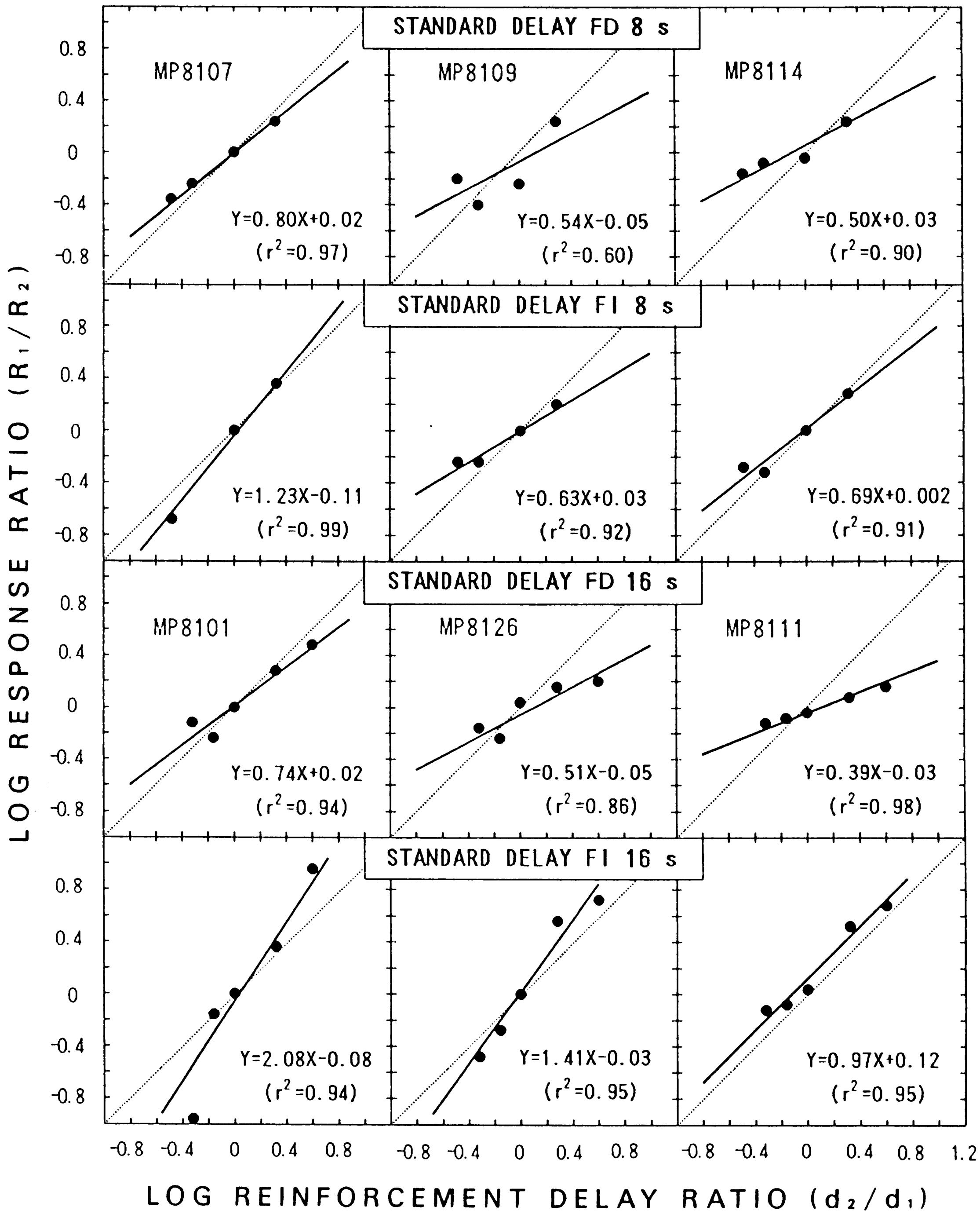

Fig. 1. The logarithm of the ratio of responses as a function of the logarithm of the ratio of delays in the FD and FI terminal-link conditions for each pigeon. The dashed lines show the locus of strict matching between response ratio and delay ratio. The solid lines show a least squares fit to the data.

shorter delay. They gave pigeons a choice between two different values of the delay defined by the duration of blackout periods, one of which was always four times longer than the other but whose absolute durations were varied across conditions (e.g., FD 1 s vs. FD 4 s or FD 32 s vs. FD 128 s). They found that for shorter and longer delays, pigeons' choice proportions were lower than the predicted value of .80.

Because the values of the slopes of the function obtained in the FI terminal links were greater than those obtained in the FD terminal links in the present study, it seems that some aspects of the FI terminal-link condition affected the matching relation to delayed reinforcers. Thus, the present results indicate that the matching relation to delayed reinforcers depends on the terminal-link conditions of a concurrent-chains schedule.

One problem, therefore, is to determine which aspects of the terminal-link conditions affect sensitivity to delayed reinforcers. As mentioned in the introduction, the stimulus and response conditions of terminal links are two factors that might affect sensitivity to delayed reinforcers. Because these factors were confounded in the procedure of Experiment 1, Experiment 2 attempted to examine these factors separately in several conditions. In addition, the present experiment also attempted to replicate the results of Experiment 1 with the reversed sequence of the terminal-link conditions, because Experiment 1 used only one sequence of conditions (i.e., from the FD to the FI terminal-link condition).

EXPERIMENT 2

METHOD

Subjects and Apparatus

The subjects were 4 homing pigeons maintained at about 80% of their free-feeding weights by additional feeding after each session. Three of the subjects were experimentally naive, and 1 subject (MP8111) had been used in Experiment 1. The same apparatus was used as in Experiment 1, except for the addition of a device for retracting the response keys. The response keys could be retracted 3 cm from the front wall at a rate of about 0.03 m per second, removing the possibility that the pigeons could peck the keys.

Procedure

The procedure was the same as that used in Experiment 1 except that only one pair of delay intervals was used, in which the longer delay was twice as long as the shorter delay (i.e., 8 s vs. 16 s or 16 s vs. 32 s). An 8-s (or 16-s) delay was associated with the right terminal link, and a 16-s (or 32-s) delay was arranged in the left terminal link. The 16-s versus 32-s delay pair was used only for MP8111.

Three keylight conditions were arranged in the terminal links: For the uncued conditions, entry into either of the terminal links changed the keylights from white to dark in the uncued-blackout condition; in the uncued-white condition, the keylight of the key just pecked remained white. (The other key was darkened, however.) For the cued condition, entry into one of the terminal links changed the keylight from white to red (or green), and the other key was darkened.

Entry into either of the terminal links either caused the retraction of both keys during each delay interval (the key-absent conditions), or the keys remained available (the key-present conditions). In the key-present conditions, responding during the delay intervals had no scheduled consequences. The two uncued conditions were used with the key-absent condition. Finally, FI terminal-link schedules were used with the uncued-white condition in order to examine the effects of the response requirement imposed by the FI terminal-link schedules.

The experiment was conducted in a replication design. The subjects were first exposed to the uncued-blackout condition and then to the uncued-white condition. The order of presentation of conditions for each subject is shown in Figure 2. Each condition was continued for a minimum of 18 sessions and until the same stability criterion as used in Experiment 1 had been achieved.

RESULTS

Figure 2 shows the choice proportions for the shorter of two delays for each subject (and the order of conditions). In general, choice proportions differed across the keylight-stimulus conditions, whereas choice proportions in the key-absent condition did not differ substantially from those in the key-present condition.

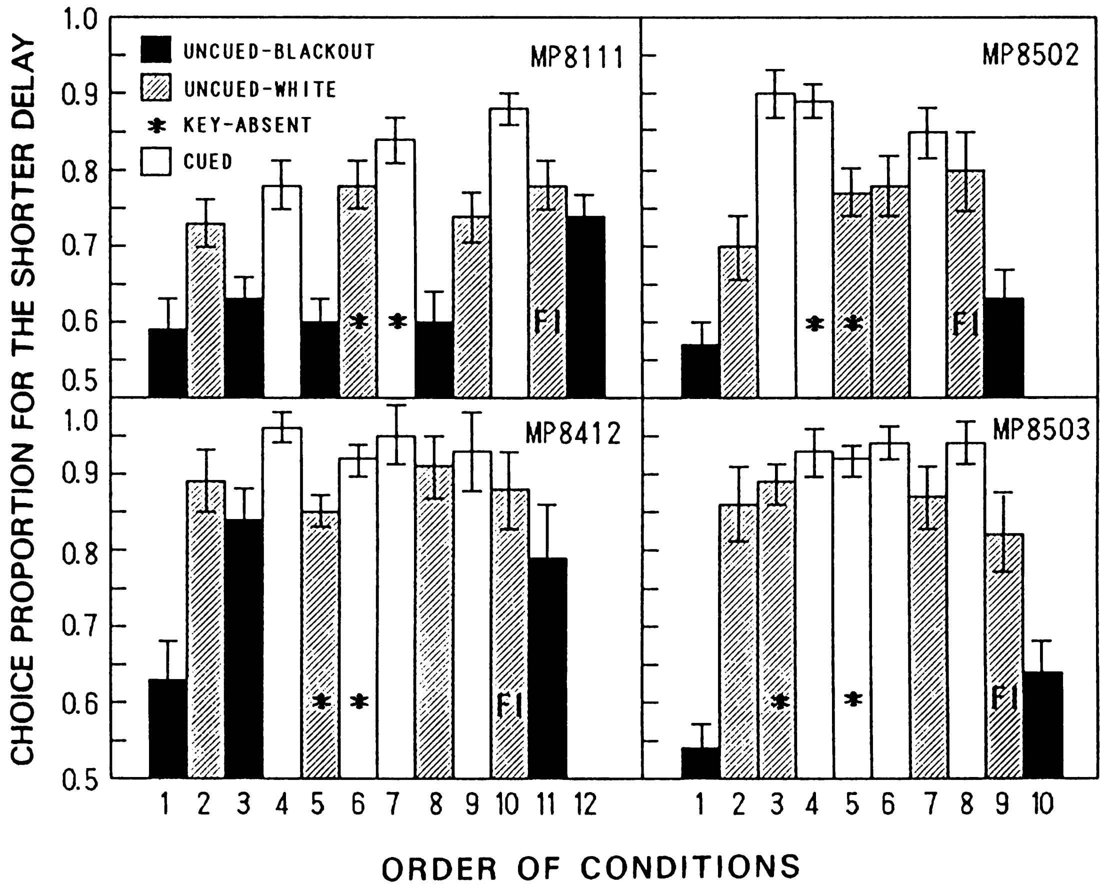

Fig. 2. The choice proportions for the shorter of two delays under several conditions for each pigeon along with the order of conditions. Brackets indicate one standard deviation. Fixed-time (FT) terminal-link schedules were used in all but one condition labeled FI, with only one pair of delay intervals (i.e., 8s vs. 16 s; 16 s vs. 32 s for MP8111).

For Pigeon MP8502, for example, the highest choice proportion was obtained in the cued condition and the lowest was obtained in the uncued-blackout condition within the first three conditions; subsequent replications confirmed these results. These results were replicated in all pigeons, although 2 of the birds (MP8412 and MP8503) showed relatively high levels of choice proportions (more than .80) in most conditions.

Table 2 summarizes the results in which each replication was averaged for each condition, and includes mean choice proportions and standard deviations and mean number of responses during initial and terminal links for each pigeon. For all but 1 pigeon (MP8111), mean number of responses emitted during the terminal links ranged from 30 to 56 in the uncued-white condition and from 124 to 205 in the uncued-white condition with FI schedules. In contrast, Pigeon MP8111, in the paired delay of 16 s versus 32 s, emitted 479 responses for the uncued-white condition and 724 responses for the uncued-white condition with FI schedules. Thus, the response requirement imposed by the FI schedules produced response rates about four times greater than those in the FT schedules, except for MP8111. There were few responses in the uncued-blackout condition for any pigeon.

For the uncued-blackout condition, the mean choice proportion for the shorter delay was .64, which was the lowest in all conditions. Mean choice proportions in the three uncued-white conditions (uncued-white condition with and without keys and with FI schedules) did not differ substantially, nor did mean choice proportions in the two cued conditions (cued condition with and without keys); choice proportions ranged from .81 to .82 in the three uncued-white conditions, whereas choice proportions in the two cued conditions were .90 and .89, respectively. Thus, the results of the present experiment showed that the keylight-stimulus conditions, rather than the response conditions, affected choice between delayed reinforcers, and that the uncued-white and cued conditions increased choice of the shorter delay relative to the uncued-blackout conditions.

Discussion

One of the purposes of the present experiment was to examine the role of response requirement during delay periods. One comparison was made between the uncued-white conditions with the FT and FI terminal-link schedules. Choice proportions did not differ substantially between these two conditions, although mean number of responses emitted was about four times larger in the FI schedules than in the FT schedules. Thus, the present results extended the generality of Neuringer's (1969) results to the situation in which a successive comparison was made between the FI and FT terminal-link schedules with a single VI 30-s schedule in the initial links.

A second purpose of the present experiment was to assess the effects of keylight-stimulus conditions during the terminal links. We used three different keylight conditions and found that choice proportions for the shorter delay increased from the uncued-blackout condition, through the uncued-white condition, to the cued condition. The present study provided a baseline for assessing the effects of keylight stimulus by using the uncued-blackout condition. Therefore, the present study can quantitatively describe the effects of the keylight-stimulus conditions relative to the baseline condition (i.e., the blackout condition); the white-key illumination increased the choice proportions by an average of 17%, and red- or green-key illumination associated with each delay increased the choice proportions by an average of 26% from the baseline condition. Thus, there was an average difference of 9% in choice proportions between the uncued-white and cued conditions. In this respect, the present results are consistent with those obtained by Williams and Fantino (1978), which showed that choice proportions in the cued condition increased relative to those in the uncued condition (cor-

Table 2

Choice proportions and standard deviations (in parentheses) for the shorter delay and number of responses for the left (L) and right (R) keys in the initial and terminal links under different terminal-link conditions. Data are obtained by averaging each replication for each pigeon.

Terminal-link conditions		Subject												
		MP8111			MP8412			MP8502			MP8503			
Keylight	Schedule type	Choice proportion	Initial-link responses (L/R)	Terminal-link responses (L/R)	Choice proportion	Initial-link responses (L/R)	Terminal-link responses (L/R)	Choice proportion	Initial-link responses (L/R)	Terminal-link responses (L/R)	Choice proportion	Initial-link responses (L/R)	Terminal-link responses (L/R)	Mean choice proportion
Uncued-blackout	FT	.63 (.06)	239/401	0/0	.75 (.11)	106/313	0/2	.60 (.05)	239/357	1/3	.59 (.06)	228/340	1/4	.64 (.06)
Uncued-white	FT	.74 (.03)	177/493	320/159	.90 (.04)	58/554	28/28	.74 (.05)	159/450	10/20	.87 (.04)	164/1,102	28/28	.81 (.07)
Uncued-white[a]	FT	.78 (.03)	127/450	0/0	.85 (.02)	90/514	0/0	.77 (.03)	158/520	1/2	.88 (.03)	91/700	0/0	.82 (.05)
Uncued-white	FI	.78 (.04)	180/639	485/239	.88 (.05)	39/323	103/91	.80 (.05)	106/425	67/57	.82 (.05)	110/490	120/85	.82 (.04)
Cued	FT	.83 (.06)	112/570	156/143	.95 (.04)	43/850	3/17	.87 (.03)	101/717	9/21	.93 (.02)	66/992	5/5	.90 (.05)
Cued[a]	FT	.84 (.03)	98/528	0/0	.92 (.02)	66/786	0/1	.89 (.02)	96/777	1/14	.92 (.02)	94/1,108	0/3	.89 (.03)

[a] Represents the key-absent condition.

responding to the uncued-white condition of the present experiment). In the uncued condition, however, the choice proportions were somewhat lower than those obtained in the present experiment. In Phase 1 of their study, mean choice proportion across pigeons was .75 in the 10-s versus 20-s condition, whereas it was .81 in the corresponding condition of the present experiment. This difference may be attributable to the lack of the position cue that was incorporated in the present procedure. In contrast, the cued condition may offset the effects of the lack of the position cue, because similar choice proportions were obtained in the cued conditions of both studies.

The present experiment employed a replication design and presented each condition in a different sequence. Therefore, the results concerning the uncued-white condition of the FI terminal-link schedules (corresponding to the FI terminal-link condition of Experiment 1) provide support for the generality of the results of Experiment 1, in which only one sequence of conditions was used (i.e., in transition from the FD to the FI terminal-link condition).

Taken together, the present results indicate that the differences in the slopes of the functions between the two conditions of Experiment 1 were due to the difference in the stimulus conditions rather than the response requirement imposed by the FI terminal-link schedules.

GENERAL DISCUSSION

The main finding of the present study was that undermatching of the response ratio to the delay ratio was evident in the FD terminal-link schedules, whereas matching or overmatching was seen in the FI terminal-link schedules in terms of the generalized matching law. These different results were due primarily to the differences in the terminal-link stimulus, rather than response, conditions; the uncued-white or cued condition in which entry into either of the terminal links left the keylight white or changed the keylight from white to different key colors (red or green) increased choice of the shorter delay relative to the uncued-blackout condition. On the other hand, there was no substantive difference between the effects of the presence or absence of keys (the key-present vs. key-absent conditions). Beyond this difference, the response requirement imposed by the FI terminal-link schedules did not affect choice of the shorter delay when compared to the FD terminal-link schedules.

Recent studies of delayed reinforcers have focused on the role of conditioned reinforcement played by a terminal-link stimulus (Dunn, Williams, & Royalty, 1987; Williams & Dunn, 1991; Williams & Fantino, 1978). In this regard, the present study provided clear evidence for quantitative differences in the conditioned reinforcing value among three terminal-link stimulus conditions. The present study employed two uncued conditions (i.e., uncued-white and uncued-blackout conditions). However, the uncued-white condition differed from the uncued-blackout condition in that the uncued-white condition was cued by darkening of the inoperative key. Thus, the uncued-white condition is closer to the cued condition. This may be one reason for the difference in the strength of conditioned reinforcement between the two uncued conditions.

The present results can be dealt with by the generalized matching equation with the sensitivity term, a. As demonstrated in Experiment 1, the value of a in Equation 1 increased as the difference between the stimuli signaling the two terminal links increased (i.e., from the uncued-blackout to the uncued-white condition). Although Experiment 2 used only one delay ratio, the results of Experiment 2 also showed that choice proportions for the shorter of two delays increased as a function of the difference in terminal-link stimulus conditions, indicating that sensitivity to delayed reinforcers was enhanced. Thus, the extent to which the conditioned reinforcing value of the terminal links affected preference is represented as the difference in the value of a in Equation 1.

Alternatively, these differences in the conditioned reinforcing value can also be predicted, in a qualitative sense, from the contingency-discriminability model (Davison & Jenkins, 1985), which states that sensitivity to reinforcement in choice depends on how well subjects can discriminate the relation between their responses and subsequent reinforcers. Applied to the present experiments, this model predicts that removing the source of discriminability of different terminal links (e.g., key location and color differences) by using the uncued-white or blackout conditions makes it more difficult for the subject to detect these contingencies; thus, sensitivity to delayed reinforcers under these uncued conditions is lowered relative to the cued condition. This discriminability account is consistent with the results obtained under the uncued-white and blackout conditions. However, the quantitative differences in choice proportion between these two uncued conditions cannot be dealt with by the contingency-discriminability model, because it does not contain any term for reinforcer delay. Therefore, the modeling of these different effects needs further work.

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